(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 May 2002 (23.05.2002)

PCT

(10) International Publication Number
WO 02/40940 A1

(51) International Patent Classification⁷: G01B 11/24, 11/25, G06T 7/00

(21) International Application Number: PCT/NL01/00818

(22) International Filing Date: 12 November 2001 (12.11.2001)

(25) Filing Language: Dutch

(26) Publication Language: English

(30) Priority Data:
1016617 15 November 2000 (15.11.2000) NL

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

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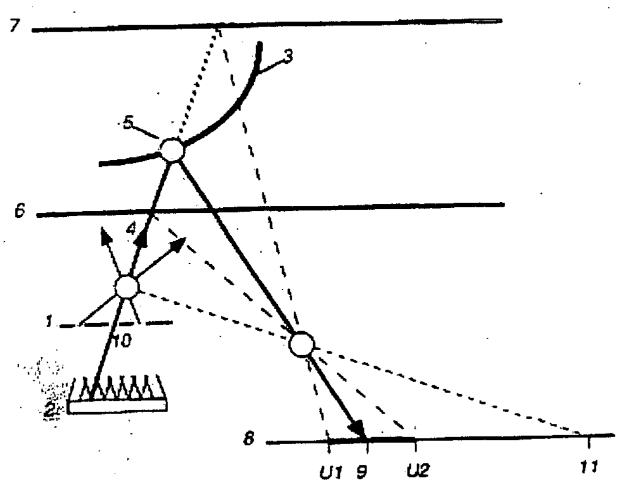
(54) Title: APPARATUS AND METHOD FOR DETERMINING THE THREE-DIMENSIONAL SHAPE OF AN OBJECT



WO 02/40940 A1

(57) Abstract: The invention relates to an apparatus for determining a three-dimensional shape of an object from a two-dimensional image, comprising a light source for illuminating the object, and a detector for forming an image of the illuminated object, wherein the light source emits a pattern of substantially needle-like light beams that are directed at the object, and wherein the detector forms an image of spots of light of the object thus illuminated by the light beams, and a processor is connected to the detector for reconstructing the shape of the object from the image of spots of light detected by the detector. The detector and the light source have a fixed position in relation to one another, the object is located between predetermined boundaries, and a mask is placed between the light source and the object for the formation of light rays, the mask being provided with an aperture pattern that is placed such that when the object is moved between the predetermined boundaries, the individual spots of the light spot image observed by the detector move along non-intersecting line sections.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Apparatus and method for determining the three-dimensional shape of an object

The invention relates to an apparatus and method for determining a three-dimensional shape of an object from a two-dimensional image, wherein a light pattern is projected on the object and an image is formed of the illuminated object.

To this end usually a light source is used for illuminating the object and a camera for forming an image of the illuminated object.

Such a method is known from the article "One-Shot Active 3D Shape Acquisition" by the authors M. Proesmans, L. van Gool and A. Oosterlinck, 13th International Conference on Pattern Recognition, Vienna, August 25-29, 1996, Vol. III, pp. 336-340. In this known method a pattern of squares is projected on the object, and a relatively complicated algorithm is necessary to be able to reconstruct the original shape of the illuminated object from the image pattern observed by the camera. There is a need for such a reconstruction system for the purpose of, among other things, quality control of surfaces of products of the agricultural industry and the metal and car industry, for the purpose of dimensional stability control of products, and for the purpose of automatic recognition of faces, which is useful for the security sector and for forensic applications.

It is observed, that from US-A-5,003,166 a system is known for remote determination with regard to an object, using an image projected on the object. By means of a camera, this image and the deformation occurring therein is determined and processed in the distance determination. The subject of this publication is therefore not connected with the present invention.

From DE-A-43 04 815 an apparatus is known for determining a three-dimensional shape of an object from a two-dimensional image, which apparatus comprises a light

source for illuminating the object, and a detector for forming an image from the illuminated object, wherein the light source emits a pattern of substantially needle-like light beams that are directed at the object, and wherein the detector forms an image of spots of light of the object thus illuminated by the light beams, and a processor is connected to the detector for reconstructing the shape of the object from the image of spots of light detected by the detector.

It is the object of the invention to provide a simple method and apparatus, whereby the determination of the shape of a three-dimensional object will be reliable, but in particular rapid.

To this end a method is proposed wherein a light pattern is projected on the object and an image is formed of the illuminated object, wherein a series of substantially needle-like light beams illuminate the object, and in an image plane a light spot image is formed of the thus illuminated object, and the shape of the object is derived from the light spot image, the method according to the invention being characterized in that the light beams are grouped in such a way that when the object is being moved, the spots of the light spot image in the image plane will move along non-intersecting line sections.

The apparatus according to the invention is effectively embodied such that the detector and the light source have a fixed position in relation to one another, in that the object is located between predetermined boundaries, and in that a mask is placed between the light source and the object for the formation of light rays, the mask being provided with an aperture pattern that is placed such that when the object is moved between the predetermined boundaries, the individual spots of the light spot image observed by the detector will move along non-intersecting line sections.

In order to achieve the aimed at rapidity with which the shape of the object can be reconstructed, it is essential for the light beams to be grouped such that when the object moves, the spots of the light spot image in the

image plane moving along non-intersecting line sections. In this way an unambiguous relationship is placed between the position of the individual spots of the light spot image in the image plane and the various places where the light beams meet the object, and from which said spots are derived. This makes it possible that the reconstructed shape of the object is only dependent on the location of the individual spots of the light spot image observed by the camera on the respective line sections, so that said shape can be determined directly from this, without the necessity of a complicated algorithm. Thanks to the invention, the reconstruction of the shape of the measured object can take place at video speed.

The reconstruction of the shape of the object thus proceeds by determining for each individual spot of the light spot image the position it takes in the line section pertaining to that spot, and subsequently deriving therefrom for each such position the spatial location where the respective light beam meets the object, after which for all spots of the spot image the respective spatial locations are compiled for the determination of the shape of the object.

The invention will now be further elucidated with reference to the drawing, which

in Fig. 1 shows with the aid of a graphical illustration the basic principle of the method according to the invention; and

in Fig. 2A and 2B, respectively, shows a light mask to be used in the apparatus according to the invention and a respective line pattern in an image plane.

With reference first to Fig. 1 reference number 1 indicates a mask, which in combination with a light source 2 forms a series of light beams that illuminates an object 3. For the sake of clarity, Fig. 1 only shows one light beam 4, with the aid of which the workings of the apparatus according to the invention will be explained. This light beam 4 results in an illuminated object spot 5 at the surface of the object 3. Incidentally, the object 3 is placed within predetermined boundaries 6 and 7. The illuminated object spot 5 is observed in the image plane 8 of a camera used as detector, where it

produces a pixel 9. This pixel 9 lies in the image plane 8 on a line section U1, U2, whose extreme boundaries are determined by the actual boundaries 6 and 7 within which the object 3 is located.

The invention produces, among other things, a solution for the problem that when there are several light beams illuminating the object 3, the ability to distinguish between the various pixels 9 in the image plane 8 of the camera threatens to become lost.

Fig. 2A shows a front view of a mask that can be used for forming the parallel light beams. The apertures 10 in the mask 2 are grouped such that the relating line sections U1, U2, as it were overlap yet do not intersect in the image plane 8 of the camera; this is shown in Figure 2B. This allows the pixels 9 in the image plane 8 to be distinguished from each other. As explained above, said line sections U1, U2 correspond with a variation in the position of the respective object spot 5 of the object 3 between the boundaries 6 and 7.

Fig. 2B shows that these line sections are determined and do not cross or intersect. This affords the possibility to directly use the position of the pixel 9 formed in the image plane 8 of the camera that corresponds with the object point 5, for the determination of the position taken up by this object point 5 in the space. For each object point 5 of the object 3 illuminated via the mask 1 by the light source 2, the position is determined on the basis of the position that the pixel 9 occupies in the image plane 8 of the camera on the respective line U1, U2, after which said position is subsequently used for deriving for each object point 5 the spatial location where the respective light beam meets the object 3. This spatial location in relation with the boundaries 6 and 7 within which the object 3 is located, is unambiguously determined by the spot that the pixel 9 occupies on the line U1-U2. A simple calculation therefore allows said spatial location to be derived from the location of the pixel 9 on the line section U1-U2. It is then possible to use for all light spots of the image plane 8 the

spatial location of the respective object points 5 pertaining thereto and determined as described above in an integral compilation for the determination of the form of the object 3.

Incidentally, it is remarked that according to the invention the system and the method are also very well suited to be used with more than one camera in order to obtain a greater accuracy when determining the shape of the object.

CLAIMS

1. An apparatus for determining a three-dimensional shape of an object from a two-dimensional image, wherein a light pattern is projected on the object and an image is formed of the illuminated object, and a detector for forming an image from the illuminated object, wherein the light source emits a pattern of substantially needle-like light beams that are directed at the object, and wherein the detector forms an image of spots of light of the object thus illuminated by the light beams, and a processor is connected to the detector for reconstructing the shape of the object from the image of spots of light detected by the detector, **characterized** in that the detector and the light source have a fixed position in relation to one another, in that the object is located between predetermined boundaries, and in that a mask is placed between the light source and the object for the formation of light rays, the mask being provided with an aperture pattern that is placed such that when the object is moved between the predetermined boundaries, the individual spots of the light spot image observed by the detector will move along non-intersecting line sections.

2. An apparatus according to claim 1, **characterized** in that the reconstructed shape of the object depends on the location of the individual spots of the light spot image observed by the camera on the respective line sections.

3. A method for determining a three-dimensional shape of an object, wherein a light pattern is projected on the object and an image is formed of the illuminated object, wherein a series of substantially needle-like light beams illuminate the object, and in an image plane a light spot image is formed, and wherein the shape of the object is derived from the light spot image, **characterized** in that the light beams are grouped in such a way that when the object is being moved, the spots of the light spot image in the image plane will move along non-intersecting line sections.

4. A method according to claim 3, **characterized** in that the shape of the object is reconstructed by determining

for each individual spot of the light spot image the position it takes in the line section pertaining to that spot, and subsequently deriving therefrom for each position the spatial location where the respective light beam meets the object, after which for all spots of the light spot image the respective spatial locations are compiled for the determination of the shape of the object.

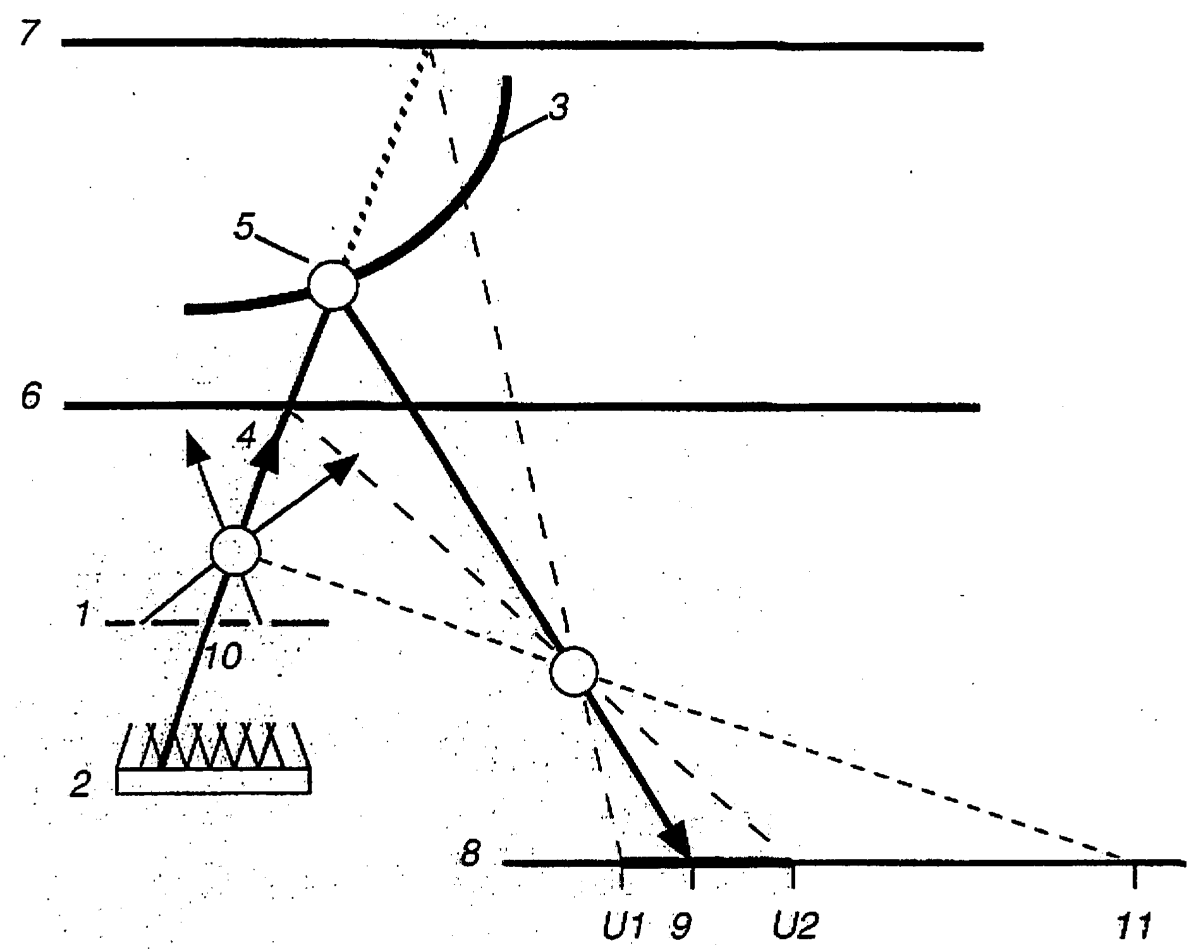


FIG. 1

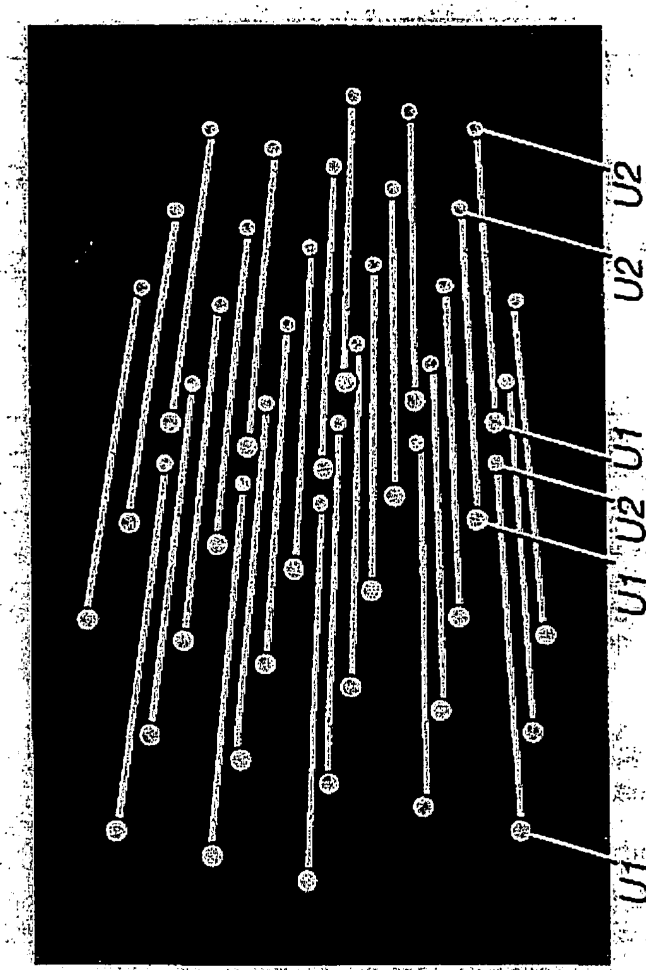


FIG. 2B

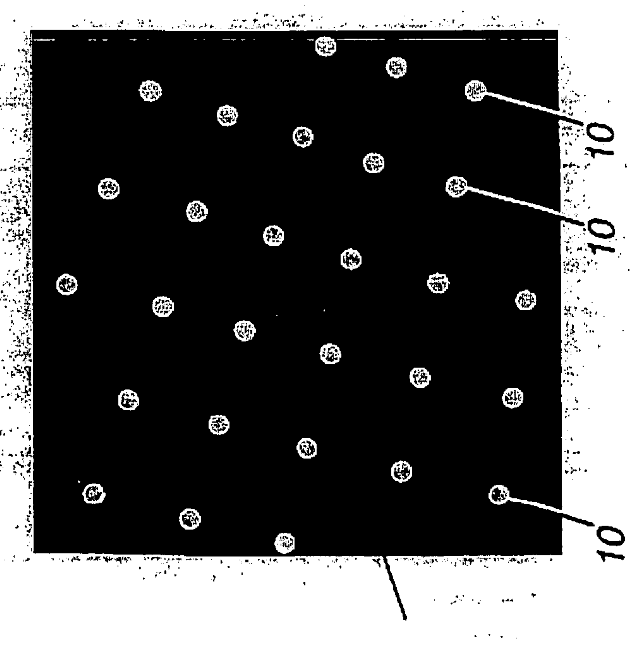


FIG. 2A

INTERNATIONAL SEARCH REPORT

In[redacted]tional Application No
PCT/[redacted]/00818

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01B11/24 G01B11/25 G06T7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01B G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 43 04 815 A (LEITZ MESSTECHNK GMBH) 18 August 1994 (1994-08-18) cited in the application * het gehele octrooischrift * figures 1,2	1-4
X	US 4 802 759 A (GORO MATSUMOTO ET AL) 7 February 1989 (1989-02-07) column 3, line 58 -column 8, line 19; figures 1-8 * samenvatting *	1-4
X	WO 91 09564 A (PHOENIX LASER SYSTEMS) 11 July 1991 (1991-07-11) page 11, line 6 -page 22, line 23; figures 1,1A,1B,2,5-14	1-4

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 February 2002	26/02/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Visser, F

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INTERNATIONAL SEARCH REPORT [redacted]

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PCT/NL [redacted]0818

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 003 166 A (BERND GIROD) 26 March 1991 (1991-03-26) cited in the application column 6, line 61 -column 10, line 32; figures 1-6	1-4

INTERNATIONAL SEARCH REPORT

[redacted]ation on patent family members

In[redacted]ational Application No
PCT/[redacted]1/00818

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 4304815	A	18-08-1994	DE	4304815	A1	18-08-1994
US 4802759	A	07-02-1989	JP	1892525	C	26-12-1994
			JP	6015968	B	02-03-1994
			JP	63044107	A	25-02-1988
WO 9109564	A	11-07-1991	US	5054907	A	08-10-1991
			AU	632674	B2	07-01-1993
			AU	7306391	A	24-07-1991
			CA	2032951	C	18-04-1995
			EP	0460209	A1	11-12-1991
			JP	4505411	T	24-09-1992
			JP	3197558	B2	13-08-2001
			WO	9109564	A1	11-07-1991
			US	5170193	A	08-12-1992
			US	5283598	A	01-02-1994
US 5003166	A	26-03-1991	NONE			

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